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Harwell et al.

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(54) **MAGNETIC FIELD DATA MODEM**

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25, 2011.

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H04L 5/16 (2006.01)

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(2013.01); **H04B 5/0087** (2013.01); **H04L**
27/38 (2013.01)

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H04L 5/1438; H04L 27/2608; H04L 27/36;
H04L 27/38; H04B 5/0031; H04B 5/0087

USPC 375/222
See application file for complete search history.

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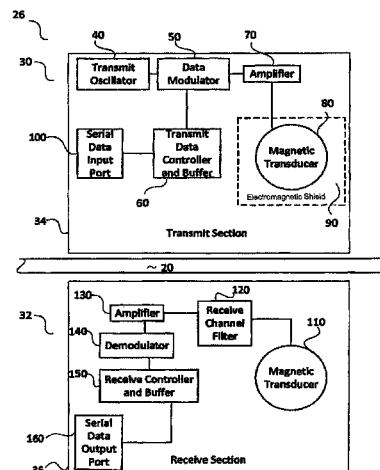
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(57) **ABSTRACT**

A magnetic field modem (26) includes an electro-magnetic radiation shielded (90) transmitter section (34) and a receiver section (36). The electro-magnetic radiation shielded (90) transmitter section (34) modulates data and transmits the data via a magnetic field through a radio frequency shield (20). The receiver section (34) receives the magnetic field through the radio frequency shield (20) and demodulates the data. The transmitter section includes an oscillator (40), a modulator (50), an amplifier (70), a magnetic transducer (80), and a non-ferrous magnetic shield (90). The oscillator (40) generates a carrier signal. The modulator (50) connects to the oscillator (40) and modulates the carrier signal with the data. The amplifier (70) connects to the modulator (50) and amplifies the modulated carrier signal. The magnetic transducer (80) connects to the amplifier (70) and converts the modulated carrier signal into a modulated magnetic signal. The non-ferrous magnetic shield (90) shields the magnetic transducer (80) and blocks emitted electro-magnetic radiation.

19 Claims, 6 Drawing Sheets



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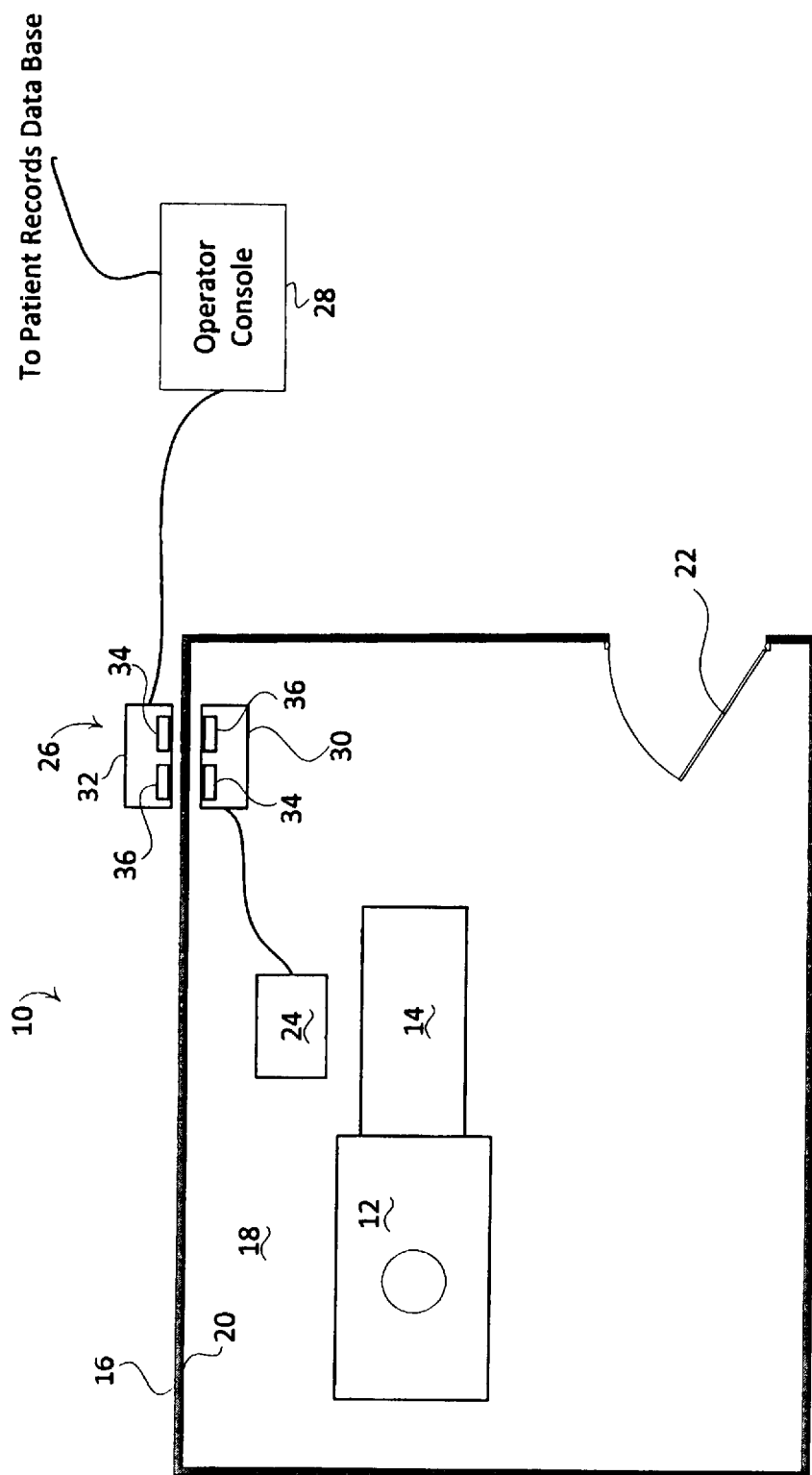


Figure 1

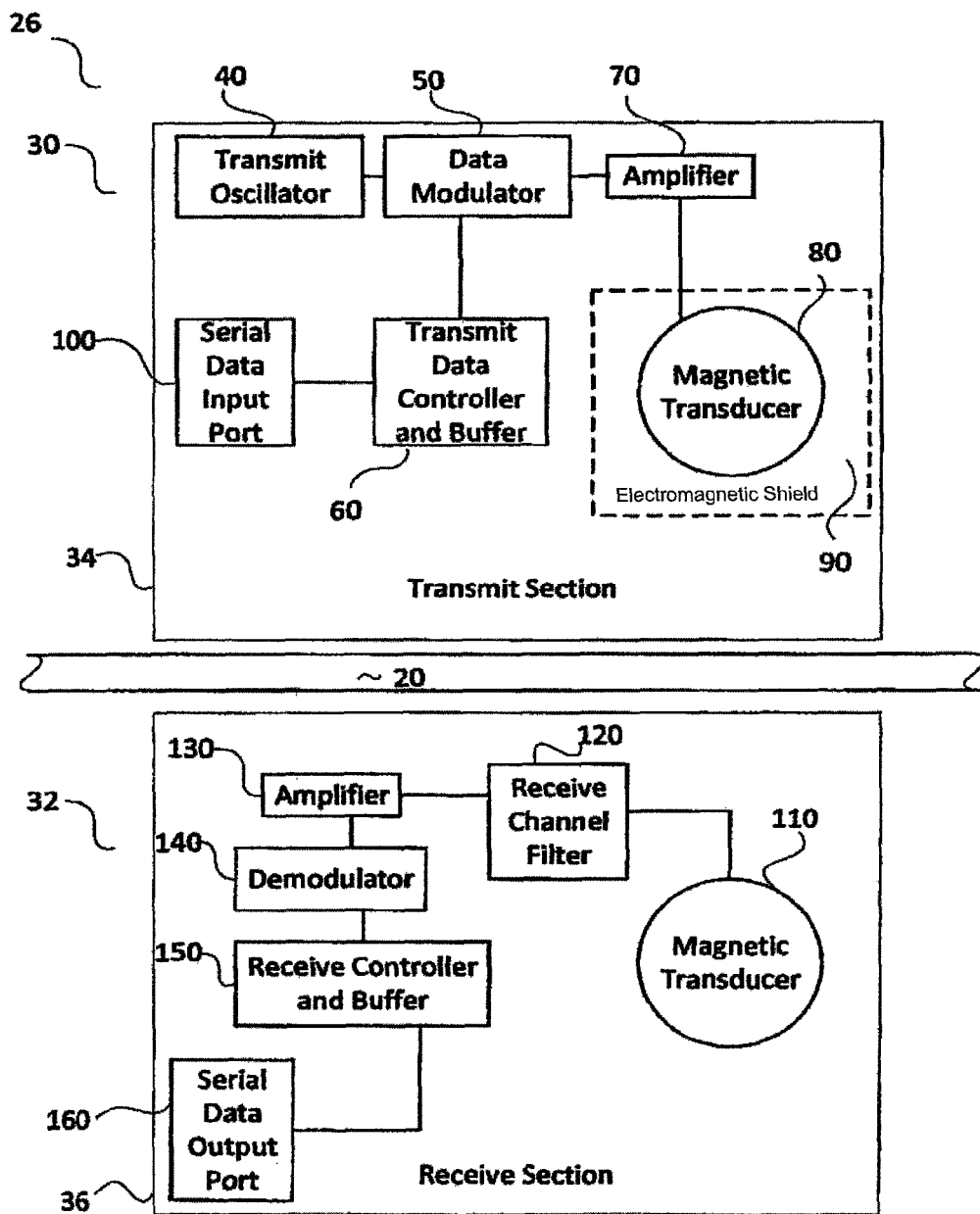


Figure 2

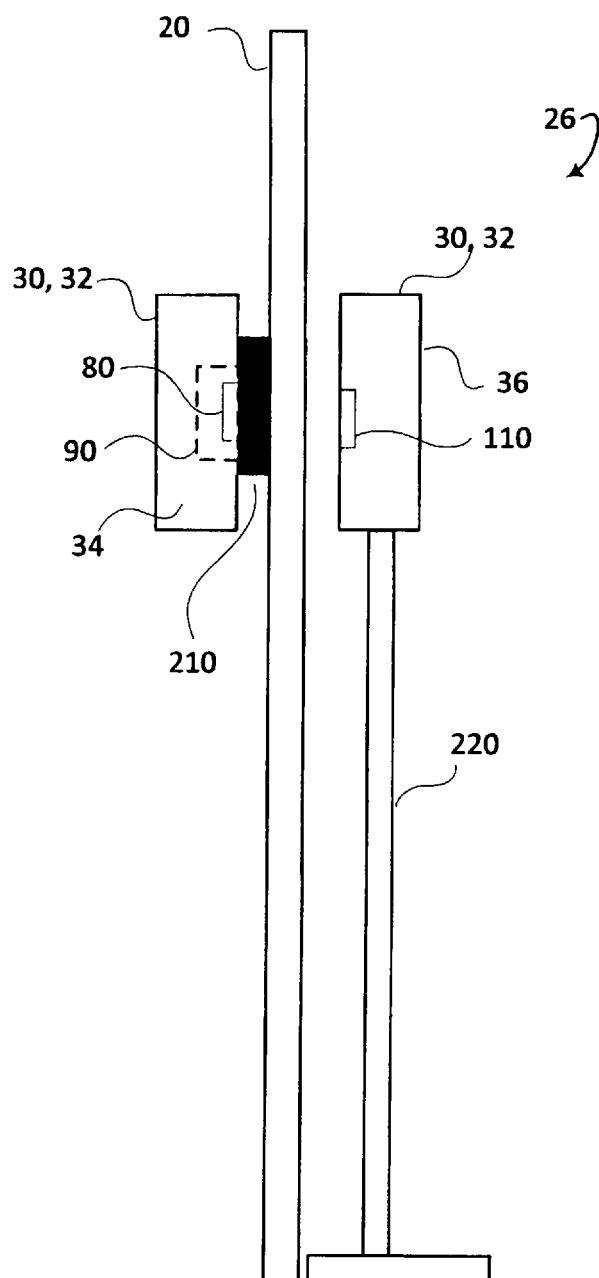


Figure 3

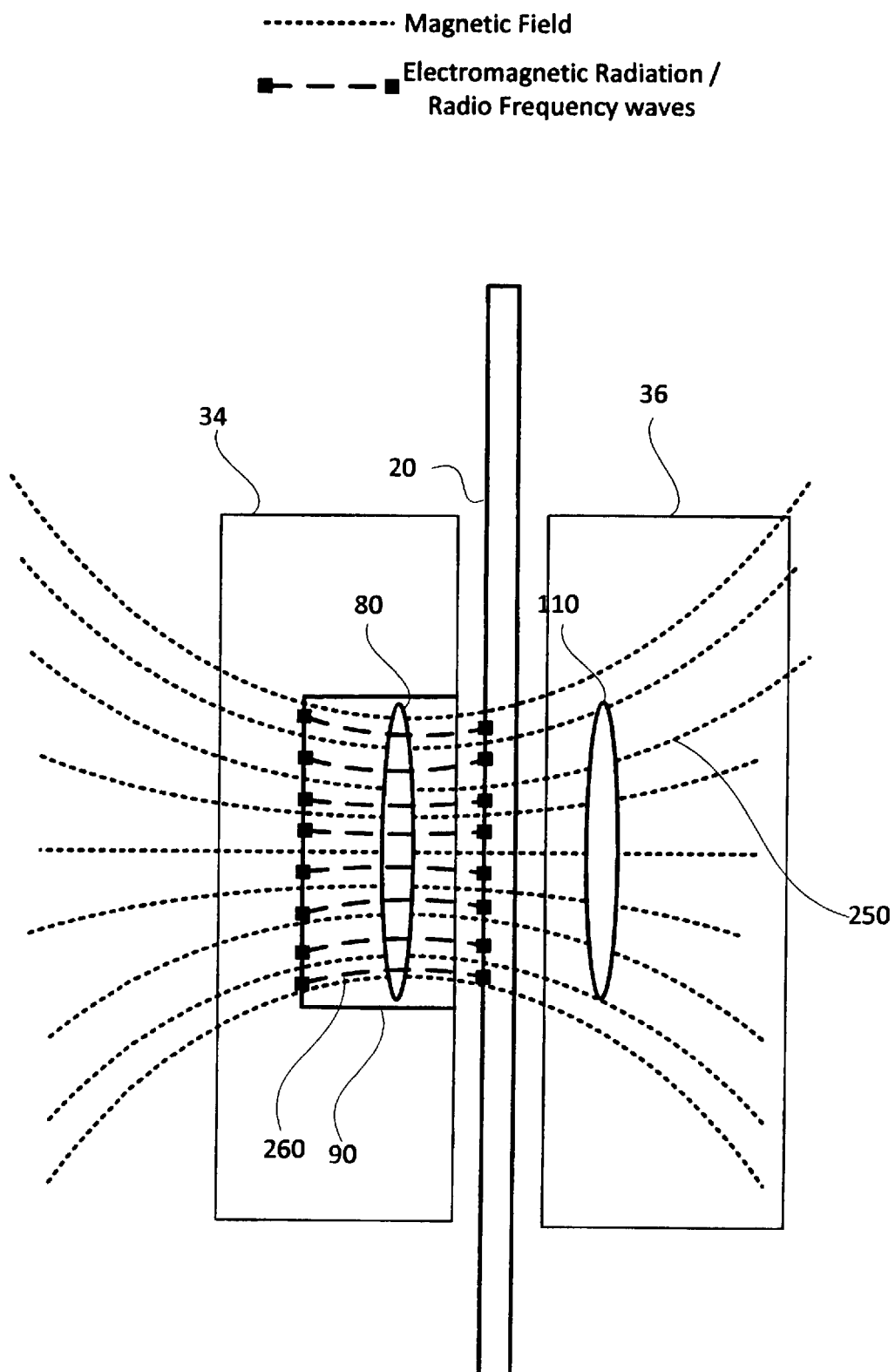


Figure 4

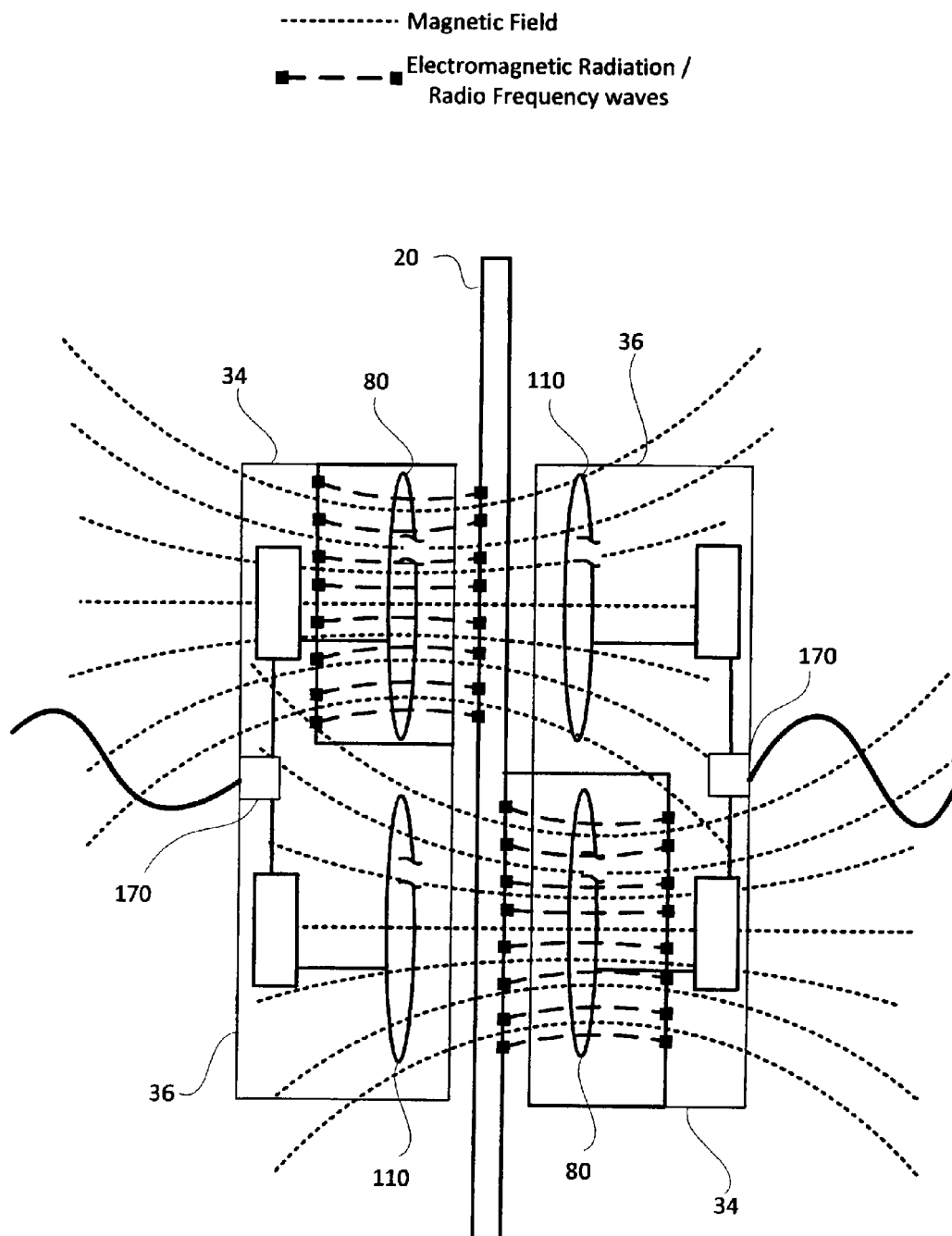


Figure 5

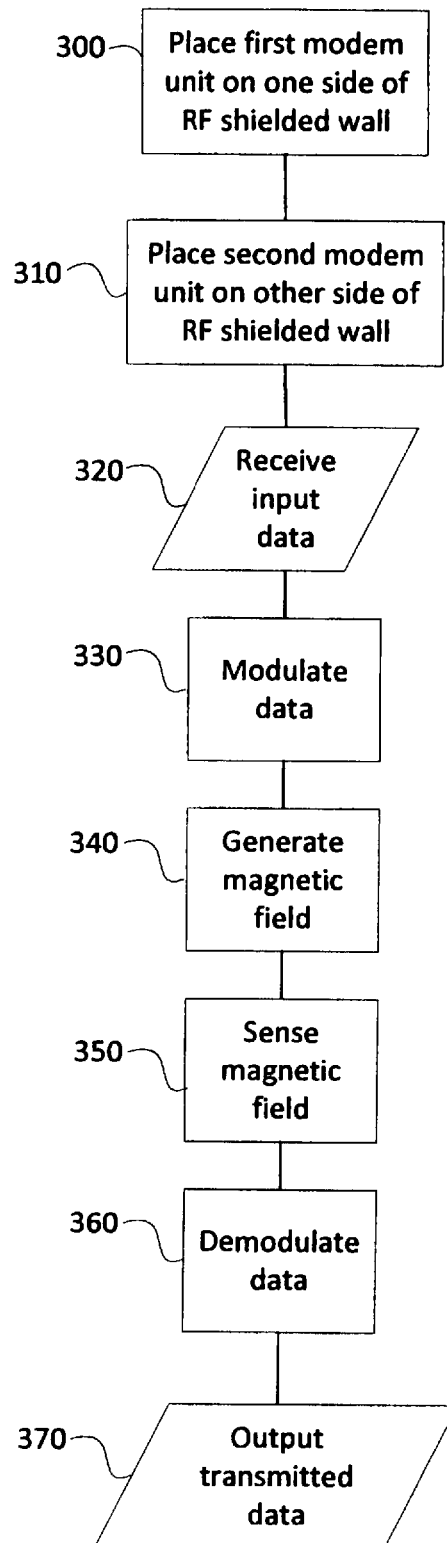


Figure 6

MAGNETIC FIELD DATA MODEM**CROSS REFERENCE TO RELATED APPLICATIONS**

This application is a national filing of PCT application Serial No. PCT/IB2012/055726, filed Oct. 19, 2012, published as WO 2013/061222 A1 on May 2, 2013, which claims the benefit of U.S. provisional application Ser. No. 61/551,025 filed Oct. 25, 2011, which is incorporated herein by reference.

The present application relates to data communications, modems, and magnetic fields, and specifically to data communications in a magnetic resonance imaging environment.

Magnetic resonance imaging is conducted in rooms which are shielded from radio frequency waves. Radio frequency (RF) coils are used to excite magnetic resonance in a subject and to receive the weak radio frequency magnetic resonance signals. Outside radio frequency waves can negatively impact the imaging. MRI scanners are typically installed in rooms which are shielded against outside radio frequency radiation. The shielding often used is non-ferrous shielding such as copper or aluminum which covers the wall, ceiling, and floor surfaces of the MR room. The shielding of the room is sometimes referred to as a Faraday cage.

Communication to and from the scanner, the subject, or an associated device with outside sources passes through this shielding. Data communicated between the control room and the scanner room includes patient parameters, patient monitoring data, MRI imaging data, and the like. Even a small hole in the shielding can leak significant amounts of stray RF contamination. Various techniques are used to allow communication with the RF shielded room. Many of these techniques involve an aperture through the shielding. Optic fibers, waveguides, and passive antennas are exemplary. Once the hole is formed, elaborate shielding efforts are implemented to stop stray RF leakage. Some MR rooms have windows with sufficient electrical conductivity, e.g. due to a fine embedded mesh screen, that they function as a part of the Faraday cage. Optical and infra-red communications can pass through such windows but requires window space and equipment located in specific places.

Communication using a RF field avoids the magnetic field frequencies used by the magnetic resonance scanner. Gradient coils typically use frequencies in the kilo-hertz range. Resonance frequencies are in the mega-hertz range.

The present application provides a new and improved magnetic data modem which overcomes the above-referenced problems and others.

In accordance with one aspect, a magnetic field modem includes an electro-magnetic radiation shielded transmitter section and a receiver section. The electro-magnetic radiation shielded transmitter modulates data and transmits the data via a magnetic field through a radio frequency shield. The receiver section senses the magnetic field through a radio frequency shield and demodulates the data.

In accordance with another aspect, a method for communicating data through a RF shield includes receiving data with a first modem unit on a first side of the RF shield. The first modem unit generates a magnetic field modulated with the first data, and transmits the modulated magnetic field through the RF shield. A second modem unit on a second side of the RF shield receives the modulated magnetic field. The second modem unit demodulates the data from the received magnetic field to recover the data, and outputs the recovered data.

One advantage is that no holes, slots, or window space are required for communications.

Another advantage is that the modem transmits through the RF shielding or RF shielded wall.

Another advantage is that the modem is easily relocated when equipment is rearranged and easily located when new equipment is added.

Another advantage is that the modem is small and easily set-up.

Another advantage is that the modem can be freely positioned in close proximity to both sides of a shielded room wall.

Another advantage is that the modem is capable of transmitting patient parameters, patient monitoring data, and MRI data from a MRI scanner room to a control room.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIG. 1 is a diagrammatic illustration of a shield MR room with the modem.

FIG. 2 is a diagram which illustrates one embodiment of the modem.

FIG. 3 is a diagram which illustrates two arrangements for placement of a modem on either side of a RF shielded room wall.

FIG. 4 is a diagram which illustrates the magnetic field generated and the blocked electro-magnetic radiation of one embodiment.

FIG. 5 is a diagram which illustrates the magnetic field generated and the blocked electro-magnetic radiation of a full duplex embodiment.

FIG. 6 is a flowchart of a method for using the modem.

With reference to FIG. 1, an MR room 10 houses an MR scanner 12 and its associated patient table or support 14. The walls 16, as well as the floor 18 and the ceiling (not shown) are covered with a grounded, electrically conductive surface, such as copper sheets 20 to form a Faraday shield. A door 22, which is large enough to pass a patient gurney, is also shielded. A door latch (not shown) cams the door tightly shut to assure contact between the door and wall shields with no gaps.

An in-room device 24, such as a patient monitoring equipment, an MR control unit, an MR signal output unit, or the like is connected with a magnetic data modem 26. The modem is connected with an operator console 28 which processes data received from the modem to generate displays, store records, or the like and/or sends signals into the MR room through the modem. The magnetic data modem 26 includes like in-room and out-of-room modem units 30 and 32, respectively.

With reference to FIG. 2, the components of one embodiment of the magnetic data modem 26 are illustrated. For simplicity, a one way modem is illustrated in FIG. 2 in which an in-room unit 30 includes a transmit section 34 and the out-of-room unit 32 includes a receive section 36. Components may be physically arranged differently and shared depending upon the configuration. Of course both the in-room and the out-of-room units can have both transmit and receive sections for two way communication. Likewise, the in-room unit can have only a receive section and the out-of-room unit only a transmit section for one-way communication in the other direction. The transmit section 34 on one side of a RF shielded wall 20 and the receive section 36 on the opposite side of the RF shielded wall is a simplex configuration. In a duplex configuration, both a transmit section 34 and

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receive section **36** are on each side of a RF shielded wall, which can operate concurrently. In a half-duplex configuration some components of the transmit and receive sections are shared where each modem alternates between operating only as a transmit section **34** or only a receive section **36** at a given point in time.

A transmit oscillator **40** determines the operating frequency modulated by the modem **10**. Various frequencies can be used, such as frequencies set aside by the regulatory bodies as ISM (Industrial, Scientific and Medical) allocations. Ideally, the oscillator frequency is different from other oscillator frequencies already in use by the scanner equipment or other equipment in the room.

A data modulator **50** is connected to the transmit oscillator **40** and a controller **60**. The controller **60** supplies the next item of data to be transmitted. The data modulator **50** encodes the next item of data on a carrier wave by modulating amplitude, frequency, phase, pulsing or any combination of these which is amplified by an amplifier **70**. A magnetic transducer **80** converts the amplified electrical signal to an oscillating magnetic signal. The magnetic signal is weak compared to electromagnetic radiation. The data remains encoded as changes in amplitude, frequency, or pulsing. The magnetic transducer **80** includes a magnetic field antenna. A loop and a solenoid are satisfactory antennas, but other antenna configurations are contemplated.

An electro-magnetic shield **90** surrounds the magnetic transducer **80** at least on the side opposite the RF shielded wall. The electro-magnetic shield **90** includes a conductive mesh or sheet such as copper or aluminum. The electro-magnetic shield **90** blocks the radio frequency electro-magnetic radiation emanating from the magnetic transducer **80** to protect the MRI scanner and other devices within the scanner room. The scanner room wall **20** or Faraday cage wall blocks the electro-magnetic radiation between the modem and the wall, but does not block the magnetic field.

The controller **60** operates to supply the next data item to be encoded by the modulator **50**. The controller **60** is connected to an input port **100** such as a serial input data port. The controller **60** uses a memory buffer to hold the data input and to supply the next data item to the data modulator **50**. Other embodiments contemplated include a parallel data input with serialization before supplying the next data item to the data modulator **50**. The in-room device **24** can convey data to the input port **100** over twisted pair wires, fiber optic, coaxially, or other known data communications techniques. Wireless communication can also be used.

The receive section **36** includes a magnetic transducer **110**. The magnetic transducer **110** is tuned for peak sensitivity to the magnetic field frequency of the modem transducer **80**. The magnetic transducer **110** converts the magnetic wave to an electric signal which is filtered by a receive channel filter **120**. The receive channel filter **120** removes unwanted noise from the signal, e.g. components off from the transmit frequency which is then input to an amplifier **130**. The amplifier **130** magnifies the signal from the filter **120** which is processed by a demodulator **140**. The demodulator **140** removes the carrier frequency to retrieve the data which the data modulator **50** placed on the carrier frequency from the oscillator **40**. The controller **150** places the data unit into a buffer and facilitates transmission to a data output port **160**. One embodiment of the output port **160** is a serial port. Other embodiments buffer the demodulated data and convert the data to digital data transmitted in parallel which reflect any connection type or method used in the data input port of the transmitter section.

With reference to FIG. 3, an embodiment of the modem **26** shows placement relative to the RF shield **20**. No penetration

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of the RF shield **20** or Faraday cage is necessary. In one embodiment, the in-room modem unit **30** and/or the out-of-room unit **32** is affixed to the wall using an adhesive **210**. Another embodiment is shown where the out-of-room modem unit **32** and/or the in-room unit **30** are mounted on a stand **220**. Precise placement on either side of the wall **16** is not necessary. The magnetic transducers are positioned close enough in proximity where the magnetic field generated on one side of a shield **20** is sensed on the other side of the shield **20**. The distance limitations are a function of the strength of the magnetic field generated and the distances between the magnetic transducer **80** of the transmit section **34** and the magnetic transducer **110** of the receive section **36**. Minimizing the gap between magnetic transducers **80**, **110** maximizes transmission efficiency.

With reference to FIG. 4, a diagram illustrates a generated magnetic field **250** and a generated electromagnetic field **260**. The RF shielding **20** or Faraday cage blocks electro-magnetic waves on one side of transmit section **34** of the in-room unit **30**. The shielding **90** blocks the RF electro-magnetic radiation going into the scanner room **10**. If the transmit section **34** is located on the out-of-room modem unit **32**, then the shielding **90** blocks the RF electromagnetic radiation affecting devices located in the control room or other area outside the scanner room. The magnetic field **250** generated by the magnetic transducer **80** of the transmit section **34** of the in-room modem unit **30** is sensed by the magnetic transducer **110** of the receive section **36** of the out-of-room modem unit **32** located on the other side of the RF shield **20**.

With reference to FIG. 5, a diagram illustrates generated magnetic fields **250** and generated electromagnetic fields **260** of a duplex configuration. Both the in-room unit and the out-of-room unit include a transmit section **34** and a receive section **36**. Both units can transmit and receive data at the same time. The carrier signals need to be different in some aspect for the bi-directional communication. Loop antennas **80**, **110** are shown in this example. The data input port and the data output port are combined in this example into a single bi-directional data port **170** for each modem unit **30**, **32**.

With reference to FIG. 6, a flowchart of a method for using the modem **26** is shown. The in-room modem unit **30** is placed on one side of a RF shield in a step **300**. The out-of-room modem unit **32** is placed on the other side of the RF shield **20** in a step **310**. Steps **300** and **310** can be reversed. Data to be transmitted is received as a step **320** in the input port **100** of at least one of the modem units **30**, **32**. The input data is modulated in a step **330**. The transmit magnetic transducer **80** generates a modulated magnetic field **250** which is transmitted through the shield **20** in a step **340**. The magnetic transducer **110** in the receiver section **36** receives the modulated magnetic field in a step **350**. The demodulator **140** in the receive section **36** demodulates the received magnetic field transmission and places the data in a buffer as a step **360**. The data is then output using the output port **160** as a step **370**. If the modem is configured for bi-directional or duplex communication, then steps **330** through **370** are performed for each direction.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

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Having thus described the preferred embodiment, the invention is now claimed to be:

1. A magnetic field modem comprising:
 - a transmitter section configured to modulate data and transmit the data via a modulated magnetic field;
 - a receiver section configured to receive the modulated magnetic field and demodulate the data; and
 - a radio frequency shield interposed between the transmitter section and the receiver section to block a radio frequency electromagnetic transmission from the transmitter section to the receiver section while passing the modulated magnetic field from the transmitter section to the receiver section.
2. The magnetic field modem according to claim 1, wherein the transmitter section further includes:
 - an oscillator which generates a carrier signal;
 - a modulator connected to the oscillator which modulates the carrier signal with the input data;
 - an amplifier connected to the modulator which amplifies the modulated carrier signal; and
 - a magnetic transducer connected to the amplifier which converts the modulated carrier signal into a modulated magnetic signal.
3. The magnetic field modem according to claim 2, wherein the transmitter section further includes:
 - an input data port which receives the input data; and
 - a controller connected to the data modulator and the input data port which makes received input data available to the modulator.
4. The magnetic field modem according to claim 1, wherein the receiver section further includes:
 - a magnetic transducer which receives the transmitted modulated magnetic field through the radio frequency shield and converts the received modulated magnetic field to a modulated data signal; and
 - a demodulator which demodulates the data signal to recover the input data.
5. The magnetic field modem according to claim 1, wherein the receiver section further includes:
 - a controller connected to the demodulator, the controller receives the demodulated input data from the demodulator and stores the input data in a buffer for transmission; and
 - an output data port which transmits the input data from the buffer.
6. The magnetic field modem according to claim 1, wherein the receiver section further includes:
 - a channel filter connected to the magnetic transducer which filters unwanted noise from the modulated data signal; and
 - an amplifier connected to the channel filter.
7. The magnetic field modem according to claim 1, wherein the receiver section and transmitter section are configured in separated units for simplex communication.
8. The magnetic field modem according to claim 1, wherein the modem includes:
 - (1) a first unit including a first-unit receiver section and the transmitter section; and
 - (2) a second unit including the receiver section and a second-unit transmitter section; wherein the radio frequency shield is further arranged to block the radio frequency electromagnetic transmission from the second-unit transmitter section to the first-unit receiver section while passing a modulated magnetic field from the second-unit transmitter section to the first-unit receiver section.

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9. The magnetic field modem according to claim 8, wherein at least one of:

- (I) the transmitter section and the first unit-receiver section of the first unit, and
- (II) the receiver section and the second-unit transmitter section of the second unit, share components.

10. The magnetic field modem according to claim 2, wherein the magnetic transducer includes a tuned loop.

11. The magnetic field modem according to claim 1, further including:

- a patient monitor device connected with the transmitter section wherein the transmitter section transmits patient monitoring data from the patient monitor device.

12. The magnetic field modem according to claim 1, wherein the radio frequency shield includes a copper sheet.

13. The magnetic field modem according to claim 1, wherein the radio frequency shield includes a non-ferrous conductive mesh.

14. A magnetic resonance suite including:

- a room shielded by a radio frequency shield;
- a magnetic resonance scanner disposed inside the room; and
- a modem comprising:

- a radio frequency electromagnetic radiation shielded transmitter section disposed inside the room which modulates data and transmits the data via a modulated magnetic field through the radio frequency shield; and

- a receiver section disposed outside the room which receives the modulated magnetic field through the radio frequency shield and demodulates the data;

wherein the radio frequency shield is interposed between the radio frequency electromagnetic radiation shielded transmitter section and the receiver section to block a radio frequency electromagnetic transmission from the transmitter section to the receiver section while passing the modulated magnetic field from the transmitter section to the receiver section.

15. The magnetic resonance suite according to claim 14, wherein the transmitter section further includes:

- an oscillator which generates a carrier signal;
- a modulator connected to the oscillator which modulates the carrier signal with the input data;
- an amplifier connected to the modulator which amplifies the modulated carrier signal; and
- a magnetic transducer connected to the amplifier which converts the modulated carrier signal into a modulated magnetic signal.

16. The magnetic resonance suite according to claim 14, wherein the modem includes:

- an in-room unit disposed inside the room that includes an in-room receiver section and the radio frequency electromagnetic radiation shielded transmitter section; and
- an out-of-room unit disposed outside the room that includes the receiver section and an out-of-room transmitter section.

17. A method for communicating data through a radio frequency (RF) shield, the method comprising:

- with a first modem unit on a first side of the RF shield: receiving first data,

- generating a magnetic field modulated with the first data, transmitting the modulated magnetic field through the RF shield;

- with a second modem unit on a second side of the RF shield:

- receiving the modulated magnetic field,
- demodulating the first data from the received magnetic field to recover the first data, and

outputting the recovered first data:
wherein the RF shield is interposed between the first
modem unit and the second modem unit to block a radio
frequency electromagnetic transmission from the first
modem unit to the second modem unit while passing the
modulated magnetic field from the first modem unit to
the second modem unit. 5

18. The method for communicating data through a RF
shield according to claim **17**, further including:
shielding radio frequency a radio frequency electromag- 10
netic radiation emitted from at least the first modem unit.

19. The method for communicating data through a RF
shield according to claim **17**, further including:

with the second modem unit:
receiving second data, 15
generating a magnetic field modulated with the second
data,
transmitting the modulated magnetic field through the RF
shield;
with the first modem unit: 20
receiving the modulated magnetic field,
demodulating the second data from the received magnetic
field to recover the second data, and
outputting the recovered second data. 25

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